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July 15, 2000

To: Delta Protection Commission

From: Margit Aramburu, Executive Director

Subject: Executive Summary of Breached Levee Wetland Study
(For Commission Information Only)

Attached is the Executive Summary of a CALFED funded study of diked areas that have restored to tidal action to generate predictions about the patterns and rates of restoration for shallow water habitat and tule marsh in the Delta.

The preliminary results are described on page v and include:

- The rate of rebuilding elevation of subsided areas is about four centimeters a year for deeper, water-covered areas.
- Exotic plants like water hyacinth and Egeria densa will dominate the deeper, water-covered areas.
- The number of introduced fishes will continue to exceed native fishes even with increased areas of water-covered habitat. The preponderance of native fishes appear during the winter and early spring when water temperatures are at their lowest.
- Shallow-water restored habitat areas do provide habitat for invertebrates.
- The tidal marsh areas (emergent marsh) and deeper water-covered areas provide very different habitats for macroinvertebrates and insects suggesting ecological "trade-offs" to restoration strategies that promote large areas and long periods of deep water-covered habitat.
- Many opportunistic fish benefit from creation of the deep, water-covered areas, but fish with more restricted habitat and food needs benefit from the predominantly intertidal habitats.

Please contact staff if you would like a copy of the complete report.

February 2000

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PRELIMINARY REPORT

Sacramento/San Joaquin Delta Breached Levee Wetland Study (BREACH)

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Acknowledgments

We wish to thank Michelle Stevens of the University of California at Davis for her vegetation expertise, and Marty Ikehara, benchmark information. Other credits to be provided for final report.

Key Words

breach, habitat restoration, hydrogeomorphology, insects, invertebrates, levees, non-indigenous species, pennywort, Sacramento–San Joaquin Delta, San Francisco Bay, salmon, sedimentation, water hyacinth, wetlands
Other key words to be provided for final report.

Executive Summary

Over 90% of the once vast tidal–freshwater wetlands of the Sacramento–San Joaquin Delta have been leveed and removed from tidal and floodwater inundation. To meet one of its major goals of "restoring ecosystem health," the California Federal (CALFED) Bay/Delta Program is considering restoration of a significant portion of these tidal wetlands by breaching and removing the levees around delta islands. A major goal of this restoration is to promote a diverse native fish assemblage, which in the delta has undergone significant reduction in population numbers in recent years. Restoring shallow-water habitat may promote primary productivity and increase spawning, rearing, and refuge habitat for native fish. The objective of our BREACH research project was to test the underlying assumptions upon which this restoration strategy is based, and to generate quantitative predictions of the patterns and rates of restoration for shallow-water habitat and tule marsh in the delta.

In 1997, we assembled our team of coastal ecologists (University of Washington), geomorphologists (University of New Orleans), hydrologists (Philip Williams and Associates) and fisheries biologists (California Dep. Water Resources) to analyze historically breached-levee wetlands as a means to predict the feasibility, patterns, and rates of restoration to natural ecological function. Breached-levee sites are former natural, freshwater tidal wetland areas that were leveed in the past and have now reverted to tidal action. We compared physicochemical and ecological indicators of wetland status at sites that were accidentally or purposefully constructed by levee breaching, often with supplemental actions such as dredge material disposal. Using the same indicators, we compared the status of both these naturally and intentionally restored wetlands to the few natural "reference" wetland sites remaining in the delta. These reference wetlands provide templates of habitat complexes (tule marsh, woody riparian vegetation, submerged and floating aquatic vegetation, tidal channel geomorphology, etc.) that we hypothesize the modern delta ecosystem can sustain.

On the basis of prior knowledge and our initial results, we have developed a conceptual model of the evolution of freshwater–tidal wetland geomorphology within breached-levee sites in the Sacramento–San Joaquin Delta. Our focus in this model was on the patterns and rates driving development of the tule marshplain because it is the predominant historical and present habitat type in reference sites, and because it is the target of many wetland restoration initiatives in the delta. Given that diking delta islands causes major subsidence relative to sea level, the key factor in restoring tule marshplain is generating intertidal habitat that can be colonized by tule vegetation. Some of the breached sites had subsided up to 6 m during the time they were leveed. Our examination of breached-levee sites in the delta indicates that freshwater–tidal marsh vegetation colonizes bare ground at intertidal elevations within several years. Vegetation establishment through natural processes on deeply subsided, subtidal areas takes significantly longer—as long as several hundred years—because of slow accretion of sediments and organic matter. Artificial means of raising bed elevations, such as deposition of dredged materials, accelerates vegetation establishment. While processes involved in establishing marsh vegetation at intertidal elevations are evident, we need to better understand the mechanisms and rates of transition between subtidal and intertidal habitats, and the role of submerged and floating aquatic vegetation (SAV and FAV) in this process.

Our emerging information on vegetation change, marsh surface accretion, and elevation change across the delta between March 1998 and May 1999 indicates patterns that partially support our conceptual model. As demonstrated at Lower Mandeville Tip, Donlon, and Venice Cut islands, tule marsh vegetation establishes quickly at intertidal elevations. However, subsequent colonization expansion is slow with an estimated maximum rate of 1.5 to 3 lineal m y^{-1}, as observed at Sherman Island. Where wave energy is high, marsh erosion may be increased further, as is evident over time at Lower Mandeville Tip. This is also consistent with observations of marsh erosion at other delta islands (e.g., Northwest Quimby Island) and with previous unpublished documentation of in-channel island marsh erosion.

Once vegetation has established, the rate of sediment accretion decreases but continues to contribute to maintenance or slow increase in marshplain elevation. All sites where feldspar marker horizons were recovered show at least 10 mm, and sometimes >20 mm of accretion during the ~13-month measurement period. More accretion occurred between March and August than between August and December. All sites in the central and western delta showed an increase in marshplain elevation (Sediment Erosion Table [SET] measurements) between June and August, which may tributed to seasonal accumulation of belowground plant biomass. Sites with high rates of accretion rarely show similarly high rates of elevation change. Dating of shallow cores from the vegetation edges of our study sites using ^{210}Pb indicates comparable long-term rates—0.8–0.9 cm yr^{-1} (Browns, Sherman islands) and 1.1 cm yr^{-1} (Sand Mound Slough)—which are of similar magnitude to the accretion data. Although current rates of sediment accretion imply that recovering intertidal habitat prior to vegetation colonization is the rate-limiting step in tule marsh restoration, our exploratory coring of subtidal habitats at Mildred Island indicated that ~0.64 m of sediment had accumulated in the intervening 15 years since breaching of the levee at this extensively subsided island. If linear (obviously, an unlikely assumption given the SET and feldspar accretion data), this rate (4.3 cm yr^{-1}) suggests that return to high intertidal elevations will require at least a century or more.

Preliminary assessment of benthic macroinvertebrates and fallout insects in the delta's shallow-water habitats shows/suggests subtle differences among sites, habitat strata, and seasons. While nematodes and oligochaetes numerically dominate all benthic core invertebrates, the composition of crustaceans varied among amphipods (predominantly *Crangonyx floridanus*, *Hyallela azteca*, *Gammarus daiberi*), isopods (*Caecidotea racovitzae*) and cladocerans. Emergent insect (Chironomidae) larvae and pupae were well represented at a few sites (especially Venice Cut), and they appeared to be more dominant in shallow-water habitat created by dredge material disposal. In the central delta, we found the Upper Mandeville Tip reference site usually had the highest benthic macroinvertebrate density and Mildred Island the least. Macroinvertebrate assemblages in the emergent marsh habitat typically were less diverse than FAV habitats; amphipods and isopods were more prominent beneath FAV although most prominent amphipod species would be different depending upon FAV plant species and site. Collembolans and chironomids dominated the fallout insect numerical composition. No distinct trends in fallout insect densities occurred among sites or habitats, but taxa composition did appear to show differences between FAV (more collembolans, psychodids, and cicadellids) and emergent marsh habitats (more chironomids).

To date, 35 fish species (8 native and 27 introduced) have been collected at all study sites. Over 98% of the total fish collected are non-migratory residents. Migratory species collected included chinook salmon (native), striped bass (introduced) and American shad (introduced). Approximately 99% of the total catch (larval and juvenile fish) were introduced species. The density of all native fish species combined was significantly higher at Upper Mandeville Tip (reference site) compared with other breached levee study sites. The density of all introduced fish species combined was significantly different among study sites. These preliminary results suggest that historical ecological functions of the reference site provide essential habitat features for native fish. Our preliminary results also show that fish distribution and occurrence is influenced by physical habitat attributes, specifically, water temperature and SAV or FAV. Native fish spawned and reared during a constricted temporal window in the early spring months under a cool temperature regime, ranging between 10° and 18°C. In contrast, introduced fish spawned and reared from late spring into the early fall when temperatures were warmer, ranging between 15° and 25°C. Densities of various fish larvae were significantly different between inshore habitats vegetated by aquatic plants and offshore–open water habitats. Juvenile fish densities were also significantly different between aquatic vegetation and open water habitats.

Food web linkages between shallow-water habitat invertebrates and fish indicated that both emergent and aquatic vegetation habitats potentially contributed to prey resources of important fishes with open-water prey entering into the diets of more planktivorous fishes at some sites during the spring. For example, juvenile chinook salmon fed predominantly on chironomid larvae and pupae (more typical of emergent marsh) as well as the amphipod *Hyallela azteca*. California silverside appeared to reflect the predominant shallow-water habitat, preying upon planktonic cladocerans (*Daphnia* sp., *Simocephalus expinosus*, *Ceriodaphnia* sp.) associated with aquatic vegetation in extensively flooded islands like Mildred Island in April but incorporating more emergent marsh macroinvertebrates (chironomid larvae/pupae, ostracods) at the Upper and Lower Mandeville Tip sites. Seasonal differences were apparent, as silverside at Mildred Island had switched to emergent marsh chironomid larvae/pupae and fallout insects (collembolans, homopterans, Araneae) in July. Both splittail and tule perch displayed diet spectra of open-water, aquatic vegetation and emergent marsh prey, including cladocerans, amphipods (*Hyalella azteca*), and chironomid larvae and pupae. Bluegill illustrated extraordinary diet diversity from all habitats, regardless of the site—indicative of a completely opportunistic feeder. We also conducted field examinations of piscivorous largemouth bass, white catfish, and striped bass and found their gut contents to include several juvenile fish, including splittail (native), threadfin shad (introduced) and inland silverside (introduced).

Because of the prominence of the introduced FAV, water hyacinth (*Eichhornia crassipes*), in the delta, we focused particular attention on food web linkages between invertebrate prey associated with water hyacinth and the native aquatic FAV, pennywort (*Hydrocotyle umbellata*). Native to Brazil, water hyacinth was introduced into the delta region in the 1940s. Both types of FAV are common to shallow-water areas of the central delta, although the Department of Boating and Waterways controls water hyacinth with chemical spraying of 2, 4-D. We predicted that macroinvertebrate taxa richness and density would be different between the two vegetation types because of distinct physical and biological characteristics of the FAV canopies. Preliminary results show that both FAV types have diverse invertebrate assemblages in their root masses, dominated by amphipods. Fish diet analyses show that these amphipods provide food for fish caught in close proximity. Dissolved oxygen levels show a marked decrease underneath water hyacinth compared with underneath pennywort and adjacent to emergent vegetation.

These preliminary results provide some intriguing interpretations to the intent and process of restoring delta wetlands by breaching levees:

- The process of rebuilding intertidal elevations, which will be readily colonized by emergent marsh vegetation, cannot be directly extrapolated from what we know about the historical formation of the delta, and it depends greatly on the extent of leveed-island subsidence and the geomorphic region of the delta. On the basis of our independent estimates from feldspar, SET, ^{210}Pb and core stratigraphy, we suggest rates of ~4 cm yr^{-1} for subtidal habitats and ~1 cm yr^{-1} for intertidal habitats, depending to a large degree on the extent of wave and current energy. Intervention through enhanced sediment input (dredge material disposal) offers one of the few mechanisms of shortening the subtidal/FAV habitat phase.
- Native tule marsh vegetation will rapidly colonize emerging intertidal elevations but submerged and floating aquatic vegetation, including introduced species such as water hyacinth and *Egeria densa*, will dominate subtidal habitats; we are uncertain what the role of aquatic vegetation is in affecting the process of transcending from subtidal to intertidal elevations.
- The occurrence and density of introduced fishes likely will continue to exceed native fishes even with increased levee-breach restoration owing to the extensive area and duration of the subtidal-SAV/FAV phase of the restoration process and the ability of introduced fishes to exploit these habitats for a greater proportion of the year. The preponderance of native fishes appears during the winter and early spring, when water temperatures are at their lowest.
- Maximum invertebrate density typically occurs at the reference site, suggesting the mature site may be more productive; because composition of benthic macroinvertebrate and fallout insect assemblages in breached-dike, shallow-water habitats is generally similar to that for reference sites, breached-dike restoration sites should rapidly contribute to the delta's emergent wetland secondary production.
- Our preliminary findings—that emergent marsh and SAV/FAV habitats demonstrate distinct differences in terms of benthic macroinvertebrate and insect contributions—suggest ecological "trade-offs" to restoration strategies that promote large areas and long periods of the subtidal habitat phase of restoration.
- Evidence that food webs supporting both native and introduced fishes derive from SAV/FAV as well as emergent marsh habitats imply that, although SAV/FAV (including exotic species) habitats support prey resources of many fishes, more opportunistic fishes would benefit from early restoration phases, while more restricted habitat/food web specialists will benefit from later stages of predominantly intertidal habitats.